PROCEEDINGS OF SCIENCE

Testing New TeV-scale Seesaw Mediators at the LHC

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We propose TeV-scale Dirac fermions producing Majorana masses of the known neutrinos via tree-level seesaw, different from standard type I and III seesaw. The employed weak five-plet with nonzero hypercharge leads to new seesaw formula $m_\nu \sim v^6/M^5$ and to empirical masses $m_\nu \sim 10^{-1}$ eV for $M \sim$ TeV new states. For a limited range of the parameter space, where $M \leq$ a few 100 GeV, the proposed mechanism is testable at the LHC via characteristic decays of Dirac type heavy leptons, produced by a Drell-Yan fusion.

35th International Conference of High Energy Physics - ICHEP2010,
July 22-28, 2010
Paris France

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[†]This work is supported by the Croatian Ministry of Science, Education and Sports under Contract No. 119-0982930-1016.

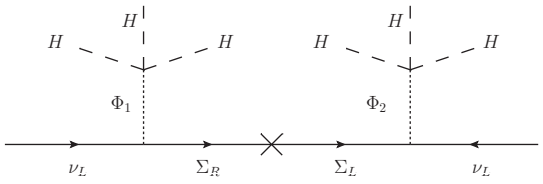
Our model [1] is based on the standard model group (SMG) $SU(3)_C \times SU(2)_L \times U(1)_Y$ content extended by vectorlike Dirac 5-plets of leptons, $\Sigma_{L,R} = (\Sigma^{+++}, \Sigma^{++}, \Sigma^{+}, \Sigma^{0}, \Sigma^{-})_{L,R} \sim (1,5,2)$, which form a Dirac mass term $\mathscr{L}_{mass} = -M_\Sigma \overline{\Sigma}_L \Sigma_R + H.c.$. They, in conjunction with additional scalar four-plets $\Phi_1 = (\Phi_1^0, \Phi_1^-, \Phi_1^{--}, \Phi_1^{---})$ and $\Phi_2 = (\Phi_2^+ \Phi_2^0, \Phi_2^-, \Phi_2^{--}) \sim (1,4,-3)$ and $(1,4,-1)$ respectively, build the gauge invariant Yukawa terms

$$\mathscr{L}_Y = Y_1 \overline{l}_L \Sigma_R \Phi_1 + Y_2 \overline{\Sigma}_L (l_L)^c \Phi_2^* + \text{H.c.} \,. \tag{1}$$

Due to the induced *vevs* v_{Φ_1} and v_{Φ_2} of new scalar fields, the light neutrino acquires a mass

$$m_\nu \sim \frac{Y_1 Y_2 v_{\Phi_1} v_{\Phi_2}}{M_\Sigma} = \frac{Y_1 Y_2 \ \lambda_1 \lambda_2 \ v^6}{M_\Sigma \ \mu_{\Phi_1}^2 \ \mu_{\Phi_2}^2} \sim v^6 / M^5 \,, \tag{2}$$

corresponding to seesaw mechanism generated by dimension nine operator shown in the figure.



Produced 5-plet pair	σ/fb
$\Sigma^{+++}\overline{\Sigma^{++}}$	180
$\Sigma^{++}\overline{\Sigma^{+}}$	270
$\Sigma^{+}\overline{\Sigma^{0}}$	270
$\Sigma^{+++}\overline{\Sigma^{+++}}$	230
$\Sigma^{-}\overline{\Sigma^{-}}$	210

The new physics scale Λ_{NP} of our model can be estimated from eq. (2) for some reasonable values of Yukawa and quartic coupling strengths λ_1 and λ_2, say $Y_1 \sim Y_2 \sim \lambda_1 \sim \lambda_2 \sim 10^{-2}$. Assuming degenerate all high scale mass parameters, we obtain $\Lambda_{NP} \simeq 580$ GeV.

Accordingly, the 5-plet seesaw mediators can be produced by $W^\pm$, Z^0 and γ Drell-Yan processes at the LHC. The associated production of the pairs $(\Sigma^{+++}, \overline{\Sigma^{++}})$, $(\Sigma^{++}, \overline{\Sigma^{+}})$, $(\Sigma^{+}, \overline{\Sigma^{0}})$, $(\Sigma^{0}, \overline{\Sigma^{-}})$ via a charged current would be a crucial test of the five-plet nature of new leptons. Some highest production rates are displayed in the enclosed table for $\sqrt{s} = 14$ TeV (to be reduced by roughly a factor of 5 for the present LHC energy of $\sqrt{s} = 7$ TeV). They are higher than for type III seesaw mediators, because of both additional and enhanced couplings to the gauge bosons.

The produced five-plet states might be recognized via characteristic decays addressed in detail elsewhere [2]. Since these states are characterized by small mass splitting within a multiplet [3], their cascade decays are suppressed. A distinguished triply charged fermion which doesn't mix with SM leptons has a characteristic decay, $\Sigma^{+++} \to W^+ W^+ l^+$. The singly charged and neutral states mix with SM particles, so that the produced pairs lead to

$$\Sigma^+ \overline{\Sigma^0} \to l^+ Z l^+ W^- \to l^+ l^+ + 4 jets \ , \ \ \Sigma^0 \overline{\Sigma^0} \to l^\pm W^\mp l^\pm W^\mp \to l^\pm l^\pm + 4 jets \,, \tag{3}$$

the lepton number violating decays with same sign dileptons and the jets as an appealing signature.

References

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[3] M. Cirelli, N. Fornengo and A. Strumia, Nucl. Phys. **B753** (2006) 178 [hep-ph/0512090].